

Hydroponics: The Potential to Enhance Sustainable Food Production in Non-Arable Areas

Abstract

In the face of growing global population and increasing pressures on arable land, the pursuit of sustainable agriculture practices has never been more critical. A soil-less cultivation method that holds immense promise for food production in non-arable regions. Hydroponics represents a paradigm shift in agriculture, offering a solution to the challenges posed by limited land availability, soil degradation, and water scarcity. Hydroponics revolutionizes plant cultivation by eliminating the need for soil. It maintains a balanced nutrient solution, ensuring stress-free and robust plant growth. When compared to traditional soil-based agriculture, hydroponics exhibits several advantages. One crucial benefit lies in water conservation. Efficient utilization of water is paramount in crop production, and hydroponics systems excel in this regard. They outperform open field farming by using water more judiciously. In contrast, traditional soil farming consumes significantly larger volumes of water. Another advantage is nutrient use efficiency. Hydroponic systems outshine soil-based farming in this aspect, as they maximize nutrient utilization for plant growth. Hydroponics offers a variety of systems, enhancing its versatility. It includes precise nutrient management, controlling factors like pH and electrical conductivity. Additionally, irrigation in hydroponics is more precise and efficient. Furthermore, hydroponic systems are often located indoors, enabling year-round crop cultivation. Favourable climate conditions and readily available water contribute to accelerated plant growth. In contrast, traditional farming relies on sprawling groundspace, limiting its potential. Hydroponic vertical farming, a common practice, optimizes space by stacking plants in trays or towers, allowing for higher plant densities in smaller areas. In summary, hydroponics offers superior water conservation, nutrient efficiency, diverse system options, and year-round crop growth potential when compared to traditional soil-based agriculture.

Keywords Hydroponics, Conservation Agriculture, Protected Cultivation, Modern Agriculture, Indoor Farming, Soil-less Farming.

Introduction

The basis of hydroponics is plant growth without soil in which nutrients are directly delivered to the water in which they are grown. A balanced mixture of nutrients is dissolved in the water for healthy plant growth without stress. One of the most significant advantages of hydroponic farming is the ability to grow crops in near-optimal conditions using Controlled Environment Agriculture. [18] Because of rising pop

ulation and growing industrializing and urbanization, the land available for cultivation is shrinking at an alarming rate. And feeding such a vast population will become increasingly challenging in the coming years so Hydroponics is the new technique is introducing in the agriculture sector. we are not become totally dependent on cultivation of land. The agricultural industry needs to solve the problems of food insecurity and provide high-quality and plentiful food.

In this review we compared traditional agriculture (soil farming) to hydroponics. [38]

The primary benefits of hydroponics include a decrease in the use of chemical pesticides, fertilizers, and other fertilizers, as well as soilless cultivation. Additionally, the use of land is more efficient, resulting in improved land surface area, reduced consumption, and better water management. These benefits help to reduce the environmental impact of hydroponics and make it an attractive crop cultivation option in a controlled environment, although the high operational costs may limit its appeal [18]. Hydroponics is a great way to make food, even though it's not the same as soil cultivation [15]. This literature review endeavours to provide a comprehensive overview of hydroponics as a sustainable food production solution. It will delve into the techniques that underpin hydroponics systems, examine their environmental and resource efficiency benefits. The hydroponic cultivation approach is flexible and there are potential enhancements that can be achieved through the implementation of simplified models; a case in point is the proposal made by Bradley and Marulanda. Their model proposed a simplified hydroponic cultivation model that required 25% of the land area used for land cultivation to be used for immediate hunger alleviation. [6] By delving into the existing body of knowledge on hydroponics, this literature review aims to contribute to a deeper understanding of its potential role in shaping the future of sustainable food production, fostering resilience in agriculture, and addressing the evolving needs of our world.

Significance of Hydroponics

By providing a variety of benefits to areas where there is no perfect soil for growing crops, Hydroponics has an even greater impact on revolutionizing agriculture. The people of these areas are provided with a source of income through hydroponics. By installing hydroponic units on land not used for farming, it can help to maximise its use. It creates opportunities for local people to set up businesses and jobs through the adoption of hydroponic facilities in areas where crops are not cultivated. And also helps in best utilization of land by setting up a hydroponics unit on the non-agricultural lands. The crops grown in hydroponics are not dependent on external environment a farmer can grow different crops in a limited space. It is more effective to combine hydroponics with Aquaponics.

Fish excreta will function as a source of nutrients for the plant, promoting healthy growth. Because of their

superior development and intake of nutrients capabilities, lettuce and spinach are the most desirable species to grow in aquaculture and hydroponics systems.

Efficacy of Hydroponics over traditional Agriculture:

(a) Water Conservation: The utilization of water is a fundamental factor in the successful cultivation and production of crops. Hydroponic systems utilize water more efficiently than open fields. Furthermore, the water consumption in soil farming is significantly greater than that of Hydroponics. When water is applied to soil, most of the water is lost due to leaching, as it is not absorbed by the plant's roots. Conversely, in Hydroponics systems, the plant is grown directly in the nutrient solution, and water continues to flow through the pipes, meaning that the water is not wasted and can be recycled and reused for other purposes. [44] This cultivation offers a huge potential approach that is indisputable and ranges of advantages to environmental benefits because of its high efficiency in using nutritional and water resources [14,41]

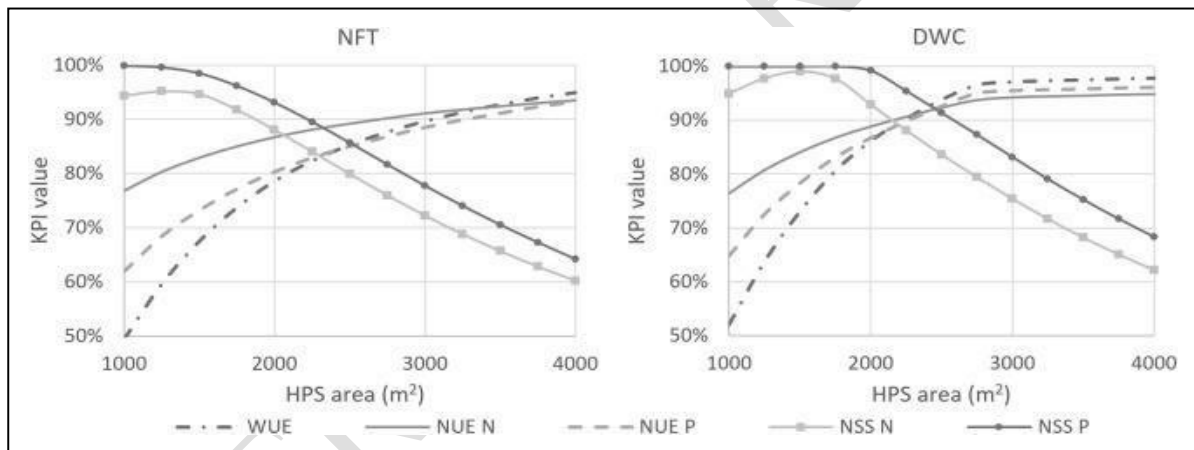


Fig1. Show the water and nutrient use efficiency of NFT, & DWC System [48].

(b) Nutrient Use Efficiency

The Nutrient use efficiency of hydroponics system is much greater than the Soil Farming. Controlling nutritional solutions and taking daily measurements of liquid nutrients is essential in order to prevent excessive salinization, as well as controlling microbial diseases and pests to prevent any loss of production [25].

Table 1. Nutrient Use Efficiency, in closed Hydroponics system:

Nutrients	Saving %
Phosphorus(P)	31.4%
Potassium(K)	52.1%
Calcium(Ca)	63.5%
Magnesium(Mg)	47.9%
Sulphur(S), Sulphate (SO ₄)	49.4%
Chlorine(Cl)	51.9%
Iron(Fe)	50.9%
Zinc(Zn)	47.9%
Manganese(Mn)	24.6%
Copper(Cu)	53.3 %
Boron(B)	47.2 %
Ammonium(NH ₄ ⁺)NO ₃ ⁻	42.1%

Source[23]

Types of Hydroponic Systems

1. Nutrient film technique the nutrient film method, NFT, is a hydroponic technique in which plants stand in a shallow stream of water containing all of the dissolved nutrients necessary for the growth of plants. This water flows between growing tanks holding plant roots. The roots of plants retrieve nutrients, and because the stream is shallow and the roots are floating in the air, the roots may also absorb oxygen [47].

The drawbacks of an NFT system are that it necessitates full coverage of all the piping system through which the nutrient solution passes. Algae growth becomes dominant even with minimal exposure to semi-open conditions [30]. The NFT hydroponic technique was developed by [2].

This method involves the continuous flow of nutrient water from a reservoir into the planting medium, which is then filtered through a gutter and distributed through the roots of the plants.

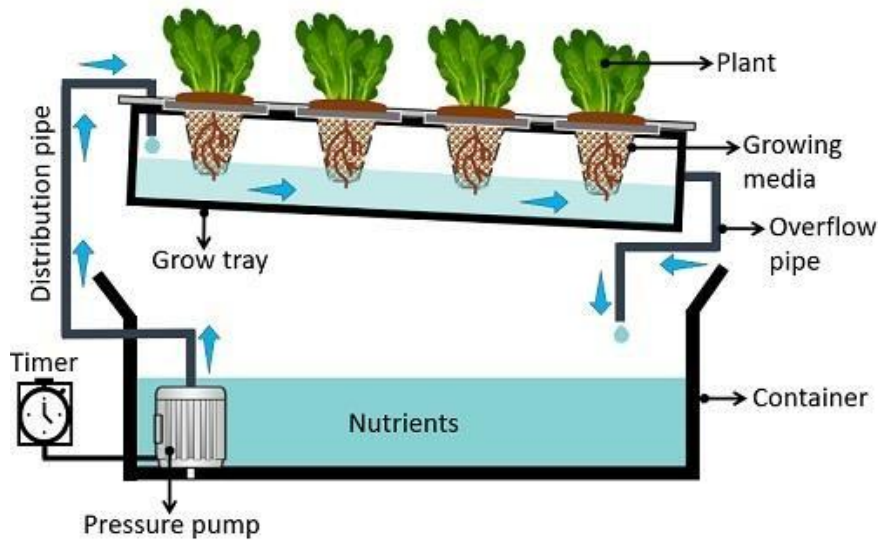


Fig2. Nutrient film technique. Source [8]

2. Dynamic root floating technique

The Taichung District Agricultural Improvement Station in Taiwan created the DRFT in 1986. The fertilizer solution is pushed through one end and circulated in the channels before being collected and returned to the tank reservoir. Instead of the NFT's continuously flowing nutrient solution system, the water pump is constantly switched on and off to change the depth of the water. Alternatively, the pump can run continuously and a drainage system can be fitted to change the depth. The concave panels underneath the floating boards are a characteristic of the DRFT. This additional space permits roots known as aero roots to develop above the nutrient solution and so obtain more oxygen [47].

In a DRFT, the air space between the sheet that holds the plants in place and the nutrient solution is left open. The roots that take up the air above the nutrient solution are called "oxygen roots" and their main job is to oxygenate the plants. DRFTs don't use active aeration like hydroponic systems do, so they don't need as much electricity from the air pump and that means lower costs. [22,24].

The DRFT resulted in a 78% decrease in electrical power consumption in comparison to the RAFT plant culture and a 10.3% decrease in total electrical power consumption for the system [45].

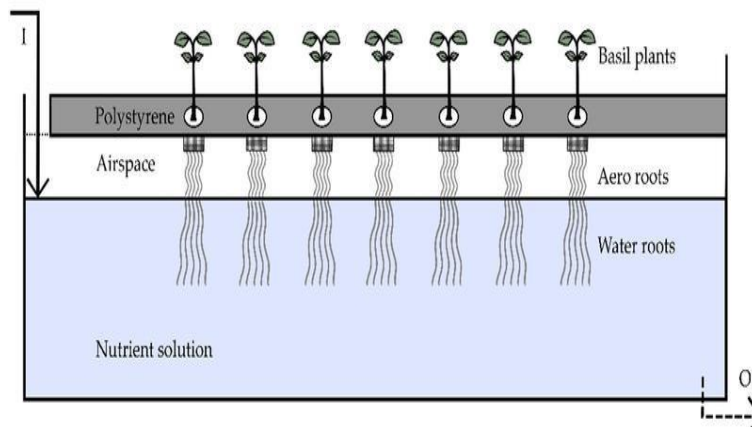
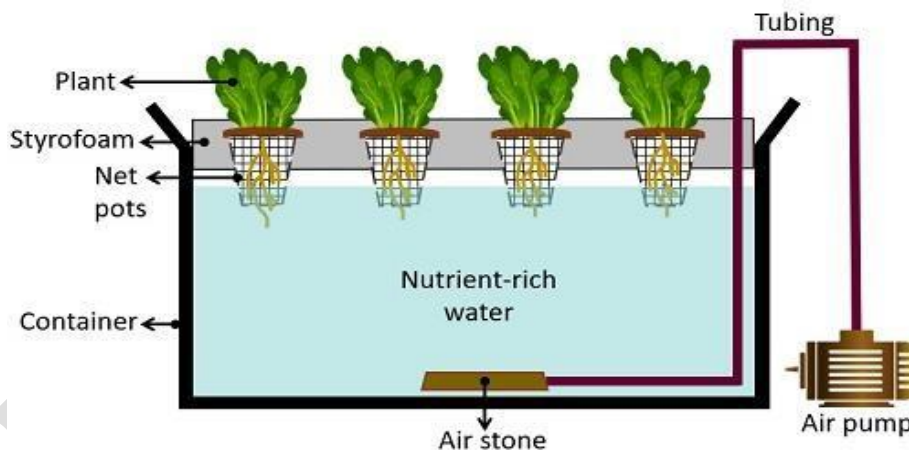


Fig3.DynamicRootFloatingTechnique.Source[37]

3. Deepwaterculturetechnique

The deep-water culture system is the easiest system to use. With this technique, known as Deep Water Culture One, you normally develop it using a reservoir that has a decent water holding capacity. Your fertilizer solution will be less volatile if you add additional water. A plant's roots remain suspended in a water and fertilizer solution that is well oxygenated in a DWC system [10]. The hydroponically cultivated lettuce crop is the most abundant in the world, accounting for approximately 99% of the hydroponic leaf area, and is priced approximately 40% higher than conventional lettuce in the DWC



[25].

Fig4.DeepWaterCultureTechnique.Source[8]

The DWC system, considered to be one of the most significant hydroponic systems, demonstrated a clear and efficient impact on vegetation growth, with the highest results for vegetative growth components for both lettuce varieties when compared to terrestrial farming systems [16].

4. Ebb and flow method

The system consists of a grow tray and a reservoir filled with a nutrient solution. A pump is used to periodically flood the grow tray with the nutrient solution which then drains away [34].

Fertilizer and water solutions are diluted gently into pro-trays; frequently, the water pump has a fixed timer that will rapidly fill growing beds at predetermined intervals.

The solution of fertilizer and water moves over the outlet and returns back into the tank when it reaches a targeted level. It releases the necessary oxygen for the growth of roots and plants, which results in oxygen and nutrients being supplied to the plants on an ongoing basis by flooding and drainage that promote healthy development [32].

The watering times are typically 20 to 30 min in most commercial ebb and flow systems, the substrate is capable of taking up at least 90% of the effective water holding capacity [9]. This is the first commercial hydroponics system to operate on the flood and drain principle. The system consists of a grow tray and a reservoir filled with a nutrient solution. A pump is used to periodically flood the grow tray with the nutrient solution which then drains away [34].

Although a considerable amount of research has been conducted on various aspects of ebb and flow sub-irrigation systems, [12].

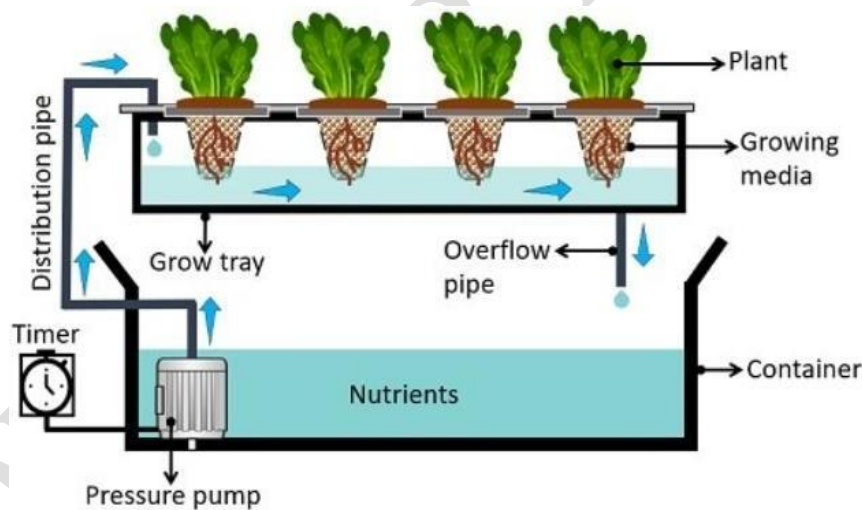


Fig5.Ebb and Flow Method. Source[8]

Greenhouse irrigation systems are often praised for their use of Ebb and Flow Sub irrigation Systems due to their advantages in terms of energy conservation compared to traditional irrigation techniques [19].

(5) Aeroponics

Aeroponics is an innovative method of cultivating crops. It is essentially an air-water cultivation system where the roots of the plant hang down inside the plant in a closed container in the dark and

in the open air to pass through the water-

feeds sprinklers. The upper part of the leaves and crown of the plant extend over the wet area. The root and crown of the plant are separated by an artificial structure.

The system uses a nutrient-enriching spray in the air through pressurized nozzles or sprinklers to maintain hyper growth under controlled conditions [26]. Aeroponic culture is an optional method of cultivating plants without soil in growth-limited environments, such as greenhouses [5]. Aeroponic seed production systems have been developed in response to rising demand for superior, excellent-quality seed production technologies [21].

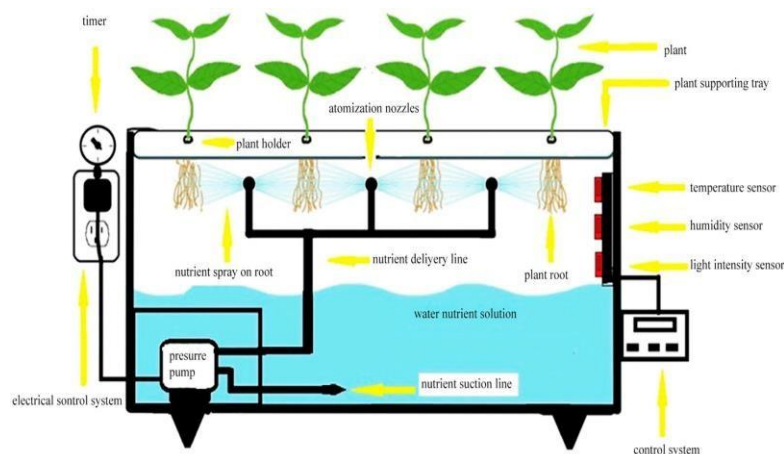


Fig6. Aeroponic system. Source [26]

Nutrient Management in Hydroponics

Managing nutrient solutions is crucial to ensuring adequate plant nutrition. To guarantee healthy plants, fertilizer solutions must be blended with a range of nutritional salts.

pH

Another common parameter in hydroponic cultivation is pH. pH is a measure of the relative concentration of hydrogen ions (H^+) to hydroxide ions (OH^-). The plant growth is highly affected by the pH value of the nutrient solution. Because plants can only ingest specific elements within a specified pH range, the pH of the root zone effectively dictates what nutrients are accessible to the plant. It states that the buffer agents are found very effective in maintaining the pH of the nutrient solution. The optimal pH range has been found 5-7 as this is the region where maximum total ion absorption occurs [7].

This study looked at how an automated system was used to control the pH and concentration of nutrients in lettuce plants. It was used to make hydroponic lettuce [33].



Fig7.pHBufferSolutions.Source[16].

Higher pH values in aquaponic solution may limit the uptake efficiency of certain essential elements, like iron, which is already limited in aquaponic solution [1]. In order for the plants to be able to take all nutrients they need; it is necessary to maintain a pH value [29]. Any disturbance in the magnitude of nutrient uptake by plants in relation to the balance of anion over cation will affect the pH of nutrient solution [27]. It is generally not advisable to use a pH lower than 5.5

When creating a hydroponic nutritional solution, certain nutrient deficiencies and inhibition of growth are often encountered outside of the acceptable range [41].

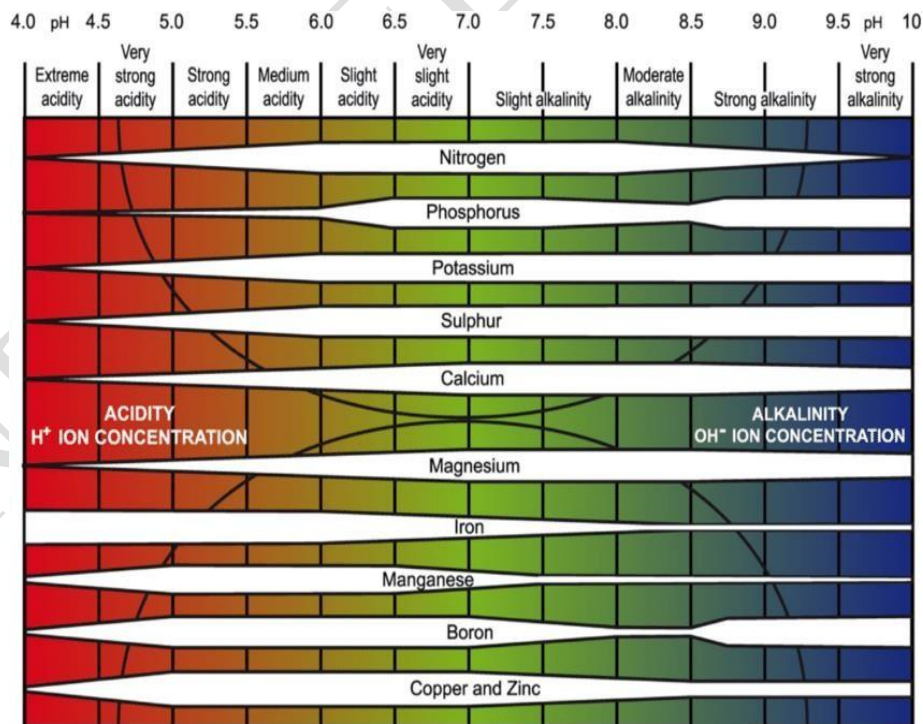


Fig 8.Influence of soil pH on the availability of nutrient elements. The width of the white shaded areas indicates the relative nutrient availability to the plant root at a given pH value [51].

Electrical Conductivity

One of those most critical factors involves maintaining the nutrition solution at the correct range of pH & EC values on a constant basis. Continuous evaluation and modification of these factors, often using pH and EC meters, ensures that the crops receive the necessary nutrients without deficit or toxicity [39]. Electrical Conductivity (EC) tells us how strong the mineral salts in the nutrient solution when they are dissolved in water. The EC is important to find out the actual concentration of the salts in the nutrient solution. It is used to monitor the use of fertilisers.

The Electrical Conductivity of the nutrient solution is maintained between **2.6-3.4 mS cm⁻¹**. [27] Higher levels of EC may hinder nutrient uptake due to an increase in osmotic pressure, while lower EC levels may have a detrimental effect on plant health and yield, as demonstrated by the work of [40].

Why EC is Important: Monitoring the EC will give you a better idea of what is really going on in your nutritional feed. There are three situations that arise with EC: one time EC remains unchanged and one time EC goes down and sometime EC will be higher. These situations will totally depend on the plant nutrient uptake capacity.

When EC remains unchanged (Constant) This situation indicates that the plant nutrient uptake is equal to the plant water uptake.

When EC goes down This indicates that the plant nutrient uptake is more than the water uptake.

When EC goes up This indicates that the plant water uptake is more than the nutrient uptake. To manage this situation, you need to dilute the solution [52].

Crop Selection and Growth in Hydroponic System:

Table 2. List of crops that can be grown on commercial level using soil-less culture. [47].

Type of Crops	Crops
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Condiments	<i>Ocimum basilicum</i> (Sweet basil), <i>Petroselinum crispum</i> (Parsley), <i>Origanum vulgare</i> (Oregano) <i>Mentha spicata</i> (Mint)
Leafy vegetables	<i>Ipomoea aquatica</i> (Kang Kong) <i>Lactuca sativa</i> (Lettuce), <i>Brassica rapa subsp. chinensis</i> (Pakchoi)
Medicinal crops	<i>Aloevera</i> (Indian Aloe), <i>Solenostemon scutellarioides</i> (Coleus)
Vegetables	<i>Phaseolus vulgaris</i> (Green bean), <i>Lycopersicon esculentum</i> (Tomato), <i>Solanum melongena</i> (Brinjal), <i>Beta vulgaris</i> (Beet), <i>Brassica oleracea var. botrytis</i> (Cauliflower), <i>Psophocarpus tetragonolobus</i> (Winged bean), <i>Capsicum frutescens</i> (Chilli), <i>Capsicum annuum</i> (Bell pepper), <i>Cucumis sativus</i> (Cucumbers), <i>Raphanus sativus</i> (Radish), <i>Allium cepa</i> (Onion) <i>Brassica oleracea var. capitata</i> (Cabbage), <i>Cucumis melo</i> (Melons),
Fruits	<i>Fragaria ananassa</i> (Strawberry)
Fodder crops	<i>Axonopus compressus</i> (Carpenter grass) <i>Sorghum bicolor</i> (Sorghum), <i>Hordeum vulgare</i> (Barley), , <i>Cynodon dactylon</i> (Bermuda grass), <i>Medicago sativa</i> (Alfalfa),
Cereals	<i>Oryza sativa</i> (Rice), <i>Zea mays</i> (Maize)
Flower/Ornamental crops	<i>Rosa berberifolia</i> (Roses), <i>Tagetes patula</i> (Marigold), <i>Chrysanthemum indicum</i> (Chrysanthemum) <i>Dianthus caryophyllus</i> (Carnations)

Irrigation Water Management in Hydroponics

The primary rationale for concentrating our efforts on hydroponics is due to the increasing evidence that hydroponics is more sustainable in economic terms than traditional agriculture [49].

All hydroponic growth techniques need a substantial quantity of clean water. The best home water supplies or agricultural water usually contain compounds and components that can impact either positively or negatively on plant growth. When it comes to hydroponic businesses, fertilizing and irrigation are two processes that go hand-in-hand. Basically, fertilizers are dissolved into the irrigation water, while irrigation water is made up of inorganic nutrients [28]. The growth of plants in hydroponic systems is contingent upon the availability of water, nutrients, and oxygen. The supply of water and nutrients can be regulated through the implementation of an effective irrigation system and the adjustment of the irrigation frequency. Similarly, the distribution of oxygen, carbon dioxide, and ethylene within the root zone has been demonstrated to be affected by medium and irrigation growth [43]. Generally, the primary purpose of irrigation is to ensure a sufficient amount of readily accessible free water (high water potential), to supply essential minerals to the plants, and to enhance oxygen levels in the root zone [28]. The open system was found to be the most water-efficient of the three systems tested, namely field culture, a closed system, and an open hydroponics substrate system [27].

Table 3. Elements with maximum level of allowable in water for Hydroponics use:

Elements	Concentration, mg/L (ppm)
Boron (B)	<1
Calcium (Ca)	<200
Magnesium (Mg)	<60
Chloride (Cl)	<70
Zinc (Zn)	<1
Sodium (Na)	<180
Carbonates (CO ₃)	<60

Source [17]

Technological Advancements and Future Prospects

Hydroponics, a soilless agricultural technique, has witnessed remarkable technological advancements in recent years. This innovative approach to farming has gained popularity due to

its potential to overcome various challenges associated with traditional soil-based agriculture, including

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water scarcity, limited arable land, and climate change. Hydroponics promotes environmental consciousness in general, and may potentially contribute to environmental sustainability by reducing typical agricultural contaminants. Foods grown hydroponically tend to have a higher nutritional content and are healthier than their alternatives. This environmentally friendly form of food production is expected to be the preferred agricultural technique in the future to meet the growing demands of the world's population [48]. Now we are discussing the latest advancements in soilless farming. One of the most recent innovations in the field of hydroponic farming is automated growth system. Sensors in this system continually track and update environmental conditions. The most recent developments in greenhouse cultivation have been the result of technological progress and wireless communication [11]. Such as temperature, Humidity Light pH nutrition level, and other variables. Hydroponics maybe an essential element in the future of exploration in outer space, as no soil has been identified that can sustain life in outer space and the transportation of soil through space shuttles appears to be impracticable [4,42] Producers are able to monitor and adapt the environment for plant development using cultivation technologies and eliminating the need of human involvement. Furthermore, smart nutrient delivers the appropriate balance of nutrients and organic compounds to encourage healthy development without sacrificing performance to assist with crop management, these equipment's may be managed remotely and connected with mobile application [35]. LEDs offer several unique advantages over traditional lighting systems since they are the most energy-efficient and environmentally friendly lighting technologies currently available [3]. The advancement of LED technology, with its capacity to pick particular wavelengths, allows for the invention of personalized light compositions for manipulating the structure of plants. Plant quality (energy distribution among various wavelengths) is frequently a combination of particular plant properties such as branching, compact size, roots, and the expansion of leaves, all of which are substantially impacted by the spectral makeup of LED light [36]. The low heat output means the light source can be positioned near the canopy, allowing for a consistent spectrum distribution while avoiding tissue damage caused by photostress [31]. The careful selection of components of the light spectrum by using LED lighting technology can significantly improve the quality-related properties/characteristics of ornamental products by influencing several physiological and metabolic processes, such as flowering, branching, rooting, pigment biosynthesis, and vase life [50].

Conclusion

Based on the review paper we conclude that the hydroponics has the promising approach to agriculture for sustainable food production in urban areas. The initial investment required to establish a hydroponic system can also be substantial, and the ongoing upkeep of the system can also be a challenge. However more research is needed to be done in Hydroponics to completely understand

thepotentialofhydroponicsinurbanareasandmakeitcosteffectivesothatthecostofestablishmentis

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not become the barrier for small farmers. So, it will become affordable and accessible to small scale farmers. Hydroponics may be an essential element in the future of exploration in outer space, as no soil has been identified that can sustain life in outer space and the transportation of soil through space shuttles appears to be impracticable.

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